P-108: FLC Resolution-Enhancing Device for Projection Displays

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Abstract

A FLC (ferroelectric liquid crystal) device based on a pixel- shift resolution-enhancement technique for projection displays has been developed using a vertically aligned FLC and a novel electrode structure. The good lateral-displacement characteristics and fast switching speed of the device enable excellent projection images.

1. Introduction

A great deal of research has aimed at developing high-resolution projection displays. Pixel-shift techniques are one way to enhance resolution when using a conventional light valve. In such a system, each image frame is divided into sub-frames and a pixel-shift device alters the pixel positions on the screen by a half pitch in each sub-frame. Driving at a high frame rate then enables the sub-frame images to constitute full-frame images. By applying two pixel-shift elements, where the first shift is done vertically and the second shift is done horizontally, the pixel-shift device can make four pixels on the screen from one original pixel on the light valve (Fig. 1).

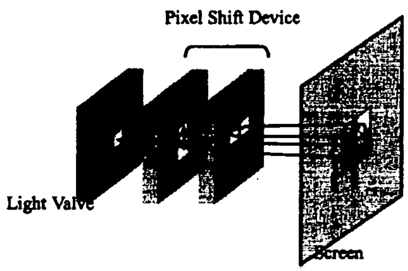

Figure 1. Pixel Shift Diagram.

Attempts have been made to apply pixel-shift technology by using ferroelectric liquid crystal (FLC) wobbling devices.[1) 2)] These devices consisted of an FLC to switch the polarization of the incident light for each sub-frame and a birefringent crystal to change the optical path depending on the polarization direction. However, in these devices the contrast ratio and color valance varied between the shifted positions, or the focal length did not agree with each optical path.

We have developed a pixel-shift device that can be used to produce excellent projection images. This device uses a vertically aligned FLC (VA-FLC) and a novel electrode structure that has multi-line shaped transparent electrodes (MLTEs) to realize better optical performance in terms of the lateral displacement of the projection light beam.

2. The Lateral-Displacement Mechanism

An FLC in a Sm C* phase has a layered structure and the c director of the molecules forms a helical structure along the direction of the layer normal. In our VA-FLC device, the helical axis is aligned vertically to the substrate surface. Figure 2 shows the relationship between the applied field and the molecular orientation of the FLC, along with the incident light behavior. Applying an in-plane electric field E to the VA-FLC layer aligns the molecules in a direction determined by the electric field. As a result, the spontaneous polarization of the molecules, represented by the arrows above the FLC molecules in the figure, becomes parallel to the electric field. In Fig. 2, the FLC molecules are aligned on the upper side by the electric field E and the projection light coming from the left is shifted upward when it passes through the device because of the tilted optical axis of the FLC molecules. When we reverse the electric field, the FLC molecules are re-aligned towards the lower side and the light is shifted downward.

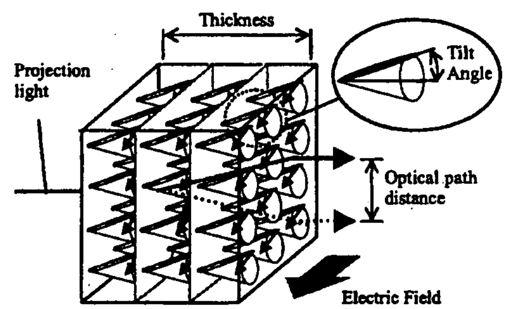

Figure 2. Schematic of the FLC Alignment.

The optical path distance between the two states above, d, which is equivalent to twice the lateral displacement, can be expressed by the formula [3)].

$$d = 2t \cdot (a^2-b^2)(\sin\psi \cdot \cos\psi) / (b^2\cos^2\psi + a^2\sin^2\psi) \quad (1)$$

$$a = 1/n_e,\ b = 1/n_o, \quad (2)$$

where t is the LC thickness, ψ is the angle between the FLC molecule's major axis and the substrate normal (the tilt angle), n_e is the refractive index for the extraordinary ray, and n_o is the refractive index for the ordinary ray. This formula indicates that the optimal lateral displacement can be obtained by controlling the LC thickness. Figure 3 shows the optical path distance between the two states calculated using this formula. The ψ value of the FLC used in this work was 25°, so we set the FLC layer

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thickness to about 50μm to obtain 6.5μm as the optical path distance, which was equal to the half pitch of the light valve we used.

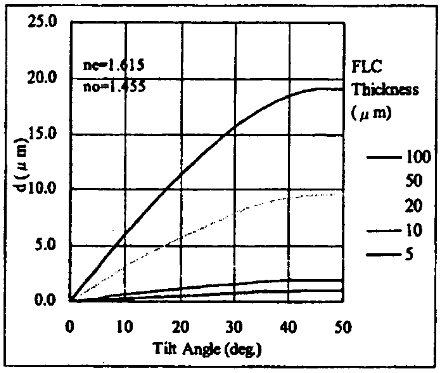

Figure 3. Optical path distance d as a function of the Tilt a Angle of FLC molecules

3. VA-FLC Device Structure

The VA-FLC device structure (Fig. 4) includes the FLC layer, an alignment layer, a plastic film spacer for FLC gap control, a dielectric layer on both sides of the FLC layer, and multi-line shaped transparent electrodes (MLTEs) of indium-tin oxide (ITO) for applying an in-plane field to the FLC. The upper and lower MLTEs are connected to the divided resistance circuit.

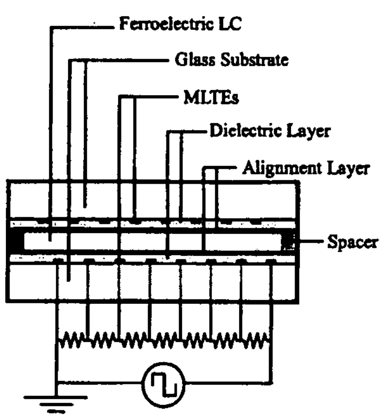

Figure 4. VA-FLC Device structure.

The electric field is controlled through the voltage difference between the neighboring electrodes, and this difference is determined by the number of electrodes and the power-supply voltage. The dielectric layers between the FLC layer and the MLTEs make the electric field more uniform at the FLC layer.

Figure 5 shows the electric field, calculated using Poisson's equation, for the device structure of Fig. 4. We solved the equation by the finite-difference method assuming a line-electrode width of 10μm, a line-electrode pitch of 100μm, 20 line electrodes, and a voltage difference between neighboring electrodes of 10 V. A uniform in-plane electric field was obtained over most of the FLC layer. The electric field generated by a single electrode pair fabricated at the spacer positions (Fig. 4) is also shown. The in-plane electric field generated by the MLTEs was clearly much more uniform than the one generated by the electrode pair.

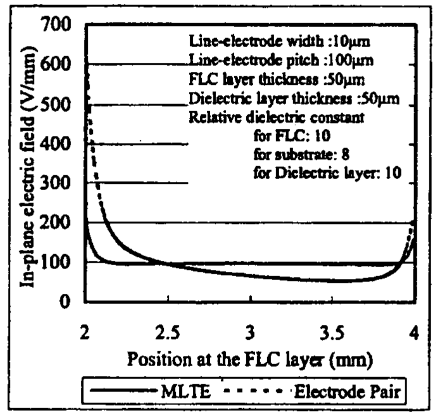

Figure 5. Generated in-plane electric field at the FLC layer.

The VA-FLC device we fabricated for the optical measurements is shown in Fig. 6. The upper and lower MLTEs were connected to the divided resistance circuit through a flexible printed circuit (FPC) from both sides of the substrates. Each substrate had 100 electrode-lines. The effective area for a pixel-shift at the center of the device was 10 x 10 mm.

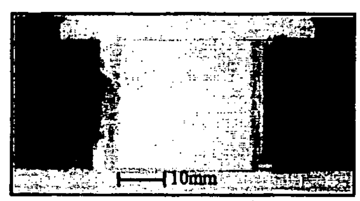

Figure 6. Pixel shift device with VA-FLC

4. Optical Characteristics

Conoscopic images of the device are shown in Fig. 7. The symmetric pattern in (A) indicates that the helical axis of the FLC was normal to the substrate surface when there was no electric field. When we applied an in-plane electric field to the device, the

center of the pattern shifted right (B), then the helical structure unwound (C) resulting in a unidirectional orientation.

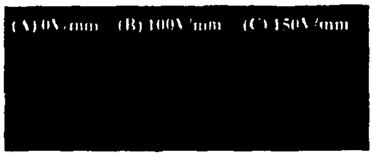

Figure 7. Conoscope images of the VA-FLC. The electric field was applied in the in-plane direction.

The relationship between the applied electric field and the tilt angle calculated from these conoscopic images is shown in Fig. 8. The tilt angle behaved in nearly the same way for each electric field direction, saturating at 25° when the applied field reached 200 V/mm. This means at each lateral displacement position we should be able to obtain consistently good optical performance as regards, for example, the color valance, focal length, and transparency.

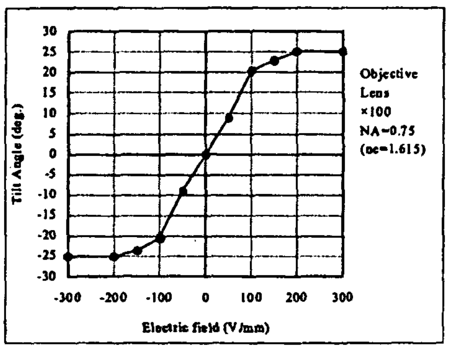

Figure 8. Tilt angle dependence on the electric field.

The measured lateral displacement characteristics are shown in Fig. 9 as functions of the electric field. The optical path distance between the two states of FLC orientation with an applied electric field up to 200 V/mm was close to 6.5μm, which is comparable to the half pitch length of conventional light valve devices. The extraction points were calculated for the optical shift distance using Eqs. (1) and (2) and the tilt angle ψ from Fig. 8. When the in-plane electric field was strong enough to make most of the molecules turn in one direction (at 200 V/mm), the calculated value agreed well with the measured value. The response time can be less than 0.7 ms under this electric field which is short enough for the conventional frame rate of 60 Hz. These results confirmed that our device should be capable of excellent performance as a pixel-shift device in a projection display.

We evaluated the resolution through contrast transfer function (CTF) measurements. CTF values were calculated using the luminance of the white and black level of the 10μm line pair pattern that could be observed with an optical microscope either through or not through the VA-FLC device. The CTF values obtained through the VA-FLC device were more than 90% of the values obtained without the device. This indicates that the deterioration of the resolution characteristics was negligible.

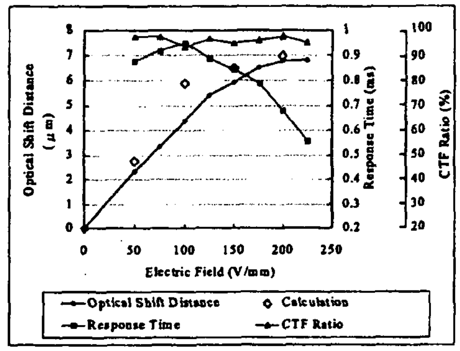

Figure 9. The lateral displacement characteristics of the VA-FLC Device as a function of the electric field.

Figure 10 shows the transmittance for the incident light colors at the pixel shift positions. Positions "A" and "B" were obtained by switching the electric field direction at 200 V/mm. Effective light means the proportion of light whose polarization direction was preserved after passing through the device and the light path is shifted normally. On the other hand, the ghost is the proportion of light whose polarization altered and worsens the contrast.

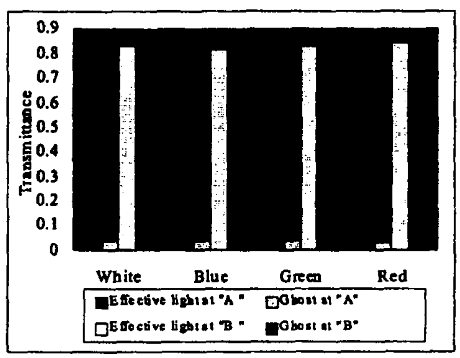

Figure 10. Transmittance dependence on each pixel shit position "A" and "B"

Although we used no AR coating on the substrate, high transmittance of the effective light was attained at both lateral displacement positions. In addition, the color balance was well preserved and the ghost component was low. These results demonstrate that the VA-FLC can provide a high contrast image with better color balance in every operational position within the

visible wavelength region than is possible with existing devices. Also, since the optical path lengths of each position are equivalent in the VA-FLC device, there is no focal point disagreement.

5. Projection Image

We obtained projection images from a projection system (Fig. 11) that consisted of a light source, a field-sequential color illumination optical system, a light valve (LCoS), projection lens, a VA-FLC pixel-shift device set between the polarizing beam splitter (PBS) and projection lens, and other optical components.

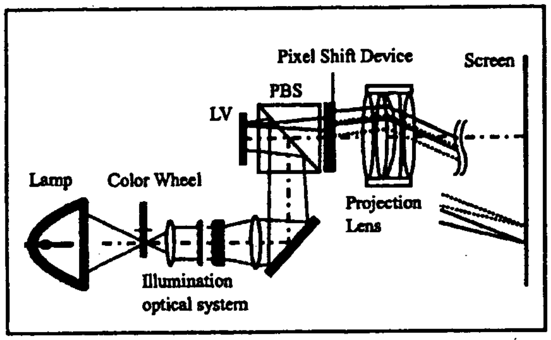

Figure 11. Projection system with the pixel shift device.

The pixel-shift device consisted of a pair of VA-FLC devices with an optical rotating element between them to enable a four-position pixel shift. The FLC switching directions in the two devices were set at a right angle to each other and the polarization rotating angle for the second VA-FLC incidence was set at 90° by the optical rotating element.

Enlarged projected images are shown in Fig. 12. The jagged edge of the character was noticeably smoothed by the pixel-shift technique and there was little of the periodic noise that is often a problem with other pixel-shift methods. This was because of the device's good lateral displacement characteristics and fast switching speed.

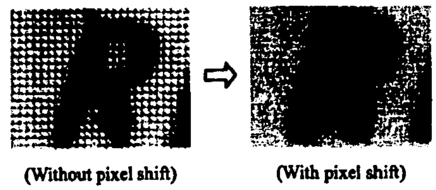

Figure 12. Projection images with and without pixel shifting.

6. Conclusion

Our vertically aligned FLC pixel-shift device provides excellent optical performance with respect to lateral displacement of the projection light beam, high transparency, and low contrast difference between pixel-shift positions in the visible wavelength region. As a result, excellent projection images can be obtained.

7. References

[1] A. Yasuda, et al.: FLC wobbling for high-resolution projectors, J. of the SID, Vol.5, No.3, p.299 (1997).

[2] D. C. Chen: Display resolution enhancement with optical scanners, Applied Optics, Vol.40, No.5, p.636 (2001)

[3] M. Françon and S. Mallick: *Polarization Interferometers*, p.140, WILEY-INTERSCIENCE (1971).

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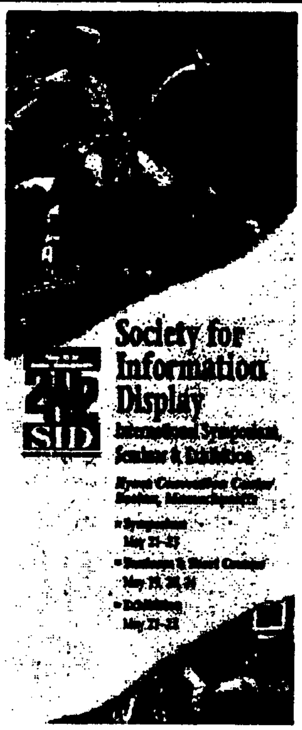

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May 19 - 24, 2002

Boston, Massachusetts

Poster Session

POSTER SESSION

Tuesday, May 21 / 4:30 - 7:00 pm / Room 302-306

PROJECTION

P.107: Reducing Gray-Value Non-Uniformities in Micro-Displays

W. De Moerloose, G. Van Doorselaer, A. Van Calster
Ghent University, Gent, Belgium

The gray-value non-uniformity in microdisplays, due to cell-gap non-u and alignment errors, can be electronically corrected. A new method t and to minimize the global and local non-uniformity of the display developed. This method was tested on a working microdisplay.

P.108: FLC Resolution-Enhancing Device for Projection Displays

T. Tokita, H. Sugimoto, Y. Matsuki, I. Katoh, K. Kameyama, Y. Takiguchi
Ricoh Co., Ltd., Kanagawa Japan

A novel ferroelectric liquid crystal (FLC) project display based on resolution-enhancement was developed using vertically aligned FLC a electrode structure. The novel lateral technique in conjunction with switching speed of the device can provide excellent projection images.

P.109: The Quality Analysis of Long Back-Focal Projection Lens

J. S. Lee
Samsung Electronics Co., Ltd., Kyungki-do Korea

The projection lens for a rear-projection TV/monitor is characterized

Points of Contact

All questions or inquiries for further information regarding this meeting should be directed to one of the following:

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Deadlines and Key Dates

Abstract / Summary	Dec. 1, 2001
Late-News Papers	Jan. 25, 2002
Digest Paper Submission	Mar. 4, 2002
Late-News Digest Paper Submission	Mar. 11, 2002
Sunday Short Courses	May 19, 2002
Monday/Friday Seminars	May 20 & 24, 2002
Symposium	May 21-23, 2002
Applications Sessions	May 21-23, 2002
Applications Tutorials	May 21-23, 2002
Exhibition	May 21-23, 2002

Exhibition

The SID Exhibition of display components and systems opens Tuesday morning, May 21 at 10:00 am and concludes at 2:00 pm on Thursday afternoon, May 23. To participate as an exhibitor, contact Joanne Morgenthal, Exhibit Manager, at 212/460-8090 x211, e-mail: jmorgenthal@pcm411.com.

NOTE ↓

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